Apr 1st, 8:00 AM

TOPEX/Poseidon Mapping the Ocean Surface

Charles A. Yamarone
TOPEX Development Flight Project, Jet Propulsion Laboratory

She!don Resell
TOPEX Ground Data System Manager, Jet Propulsion Laboratory

David L. Farless
TOPEX Mission Design Lead Engineer Jet Propulsion Laboratory

TOPEX/POSEIDON--MAPPING THE OCEAN SURFACE

Charles A. Yamarone, Manager
TOPEX Development Flight Project
Jet Propulsion Laboratory

Sheldon Rosell
TOPEX Ground Data System Manager
Jet Propulsion Laboratory

David L. Farless
TOPEX Mission Design Lead Engineer
Jet Propulsion Laboratory

ABSTRACT

Global efforts are under way to model the Earth as a complete planet so that weather patterns may be predicted on time scales of months and years (Reference 1). A major limitation in developing models of global weather is the inability to model the circulation of the oceans including the geostrophic surface currents. The National Aeronautics and Space Administration (NASA) will soon be initiating a satellite program to correct this deficiency by directly measuring these currents using the science of radar altimetry. Measurement of the ocean topography with broad, frequent coverage of all ocean basins for a long period of time will allow the derivation of the spatial and temporal behavior of surface ocean currents. The TOPEX/POSEIDON mission is a cooperative effort between NASA and the French Centre National d'Etudes Spatiales (CNES). This paper describes the goals of this research mission, the data type to be acquired, the satellite and sensors to be used to acquire the data, and the methods by which the data are to be processed and utilized.

INTRODUCTION

The oceans of the world have a profound effect on the daily lives of everyone and, in fact, on the very existence of life on this planet. The oceans ameliorate the climate in all regions of our world. They support fisheries which supply seafood and fertilizers to aid in the supply of other foods. They carry the bulk of the world's commerce, they serve as playgrounds, and they influence the quality of our lives in many ways.

The key to the ocean's influence on life is the general circulation of its currents. These currents carry about half of the heat which moves from the equatorial regions to higher latitudes and mollifies the climates of both regions (Reference 2). Currents carry nutrients from the depths to the surface where they sustain the plankton and the food chain that culminates in the world's great fisheries. Strong ocean currents affect world shipping and weak currents disperse wastes dumped into the sea (Reference 3).

Many things about the ocean are poorly understood, largely because the ocean is so difficult to observe. It is a global fluid, and like the atmosphere appears to have both a climate and a weather. But unlike meteorologists, oceanographers have no global observation system, only fragmentary and ephemeral observation systems. There are several reasons for this paucity of observations, but the primary one is that it is extremely difficult to take the measure of the ocean by in situ observations. Since the ocean is a global, dynamic system, world-wide observations, repeated at frequencies of hours or days over months and years are necessary to obtain the needed data. Satellite systems can provide this kind of coverage of the ocean surface using remote sensing techniques at frequencies for which the atmosphere is semi-transparent (Reference 4). This concept has been demonstrated by the proof-of-concept Seasat-A mission in 1978. Though this mission was short lived, it accomplished its basic task of assessing the value of microwave sensors for remote sensing of sea-surface winds and temperatures, ocean wave heights, internal waves, atmospheric water content, sea ice, topography of the ocean surface, and shape of the marine geoid (References 5 and 6).

SATELLITE ALTIMETRY

One specific satellite measurement of the ocean surface is the use of a microwave-frequency radar altimeter to measure the surface elevation of the ocean to great accuracy. Data from such measurements can be used to develop topographical maps of the ocean showing slopes relative to the equipotential surface. These slopes are caused primarily by tides and geostrophic currents. Correcting for tides allows the measured slopes to be used to determine the locations, magnitudes, and time variability of the geostrophic currents. Radar altimeter data taken over ocean surfaces also contains information on the height of the surface waves and the speed of the surface wind. The altitude of the satellite above the ocean surface is determined by a precision measurement of the time required for a transmitted pulse to reflect from the surface and return to the satellite. The shape and amplitude of the returning pulse are used to derive the wave height and wind speed.

Satellite altimetry has been demonstrated and proven over the last 10 years or so on the Skylab program, on GEOS-3, and on Seasat. The precision in the ability of these altimeters to perform the basic measurement of the distance from the satellite to the mean ocean surface has improved over this time period from about 1 m for the Skylab altimeter to about 5 cm for the Seasat altimeter. Seasat reached a precision in its altimetric measurement which demonstrated the ability of altimetric satellites to study mesoscale variability of surface geostrophic currents and has provided impressive evidence of the potential ability of satellite altimetry to improve our understanding of the permanent ocean circulation (Reference 4).

As with any seemingly simple measurement which must be made to great precision, there are many factors to be included or accounted for in the final analysis of the measurement performance. Figure 1 is an illustration of the method by which the basic altimetric measurement is reduced to an ocean surface elevation. The height of the satellite above the reference ellipsoid (a mathematically described figure) is determined by precise orbit calculations based on radio frequency doppler tracking data and/or laser tracking data. The geoid is the surface that the ocean would assume as a result of the gravitational potential and rotation of the Earth if there were no waves, tides or currents. (An accurate model of the gravitational field of the Earth is necessary to the determination of both the geoid and the satellite position.) The altitude measurement itself must be corrected for the effects of propagation through the wet and dry components of the troposhere and through the electronically active ionosphere, for instrument effects (delays, timing errors, etc.), and for the effects of the sea state on the reflected signal. Once the ocean topography relative to the geoid is derived, it is then necessary to subtract the effects of tides before the effects due to currents can be highlighted.

Key requirements for an ocean topography mission have been developed based on the goal of deriving the spatial and temporal variability of the ocean currents. The altitude of the ocean surface relative to the marine geoid must be measured to an accuracy of 14 cm along a grid of ground tracks which repeat every few days (e.g., 3 to 20 days) over a time period of from 3 to 5 years. The grid of ground tracks must cover all of the world's oceans, including the Southern Ocean as far south as the Drake Passage between South America and Antarctica. The ground tracks must repeat to an accuracy of + or -1 km on the surface, and the north-bound and south-bound ground tracks must intersect at relatively orthogonal angles to allow the resolution of the topography in the latitudinal and meridianal directions. Finally, the frequency at which samples are repeated at each point on the grid must not allow major tidal componants to be aliased into the topography measurements.

TOPEX/POSEIDON MISSION DESCRIPTION

For some years the Jet Propulsion Laboratory (JPL), under contract to NASA, has been studying a precision altimetric oceanography mission called the Ocean Topography Experiment (TOPEX). At the same time, CNES has been planning an oceanographic satellite experiment called POSEIDON. A detailed, joint U.S./French Phase B study of the possible joining of these two projects on a single space mission was completed in 1984 (Reference 7), resulting in the decision to propose a joint mission, to be called TOPEX/POSEIDON. The joint mission would involve a U.S. satellite, carrying U.S. and French instrumentation and to be launched by a European Ariane launch vehicle provided by the French (Reference 8).

The goal of the TOPEX/POSEIDON mission is to increase substantially our understanding of global ocean dynamics by making precise and accurate observations of oceanic topography for several years; to process and verify the topography measurements and distribute them in a timely manner, together with other geophysical data, to science investigators; and to lay the foundation for a continuing program to provide long-term observations of the oceanic circulation and its variability. (Reference 9)

The specific TOPEX requirement is to measure the oceanic topography with a combined accuracy from all error sources of approximately 14 cm. The factors that contribute significantly to the overall measurement accuracy are altimeter errors, media errors, and orbit errors. The current measurement budget for the TOPEX ocean topography measurement is shown in Table 1. Note that the dominant error source is the orbit determination uncertainty and that the major error in this area is that due to the gravity model.

Science Sensors. To provide these observations, the TOPEX/POSEIDON satellite will carry a dual-frequency altimeter capable of measuring the height of the satellite above the ocean with an instrument precision of + or -2.0 cm. The height measured at the two different frequencies (13.6 GHz and 5.3 GHz) provides a first-order correction for the pulse delay in the ionosphere, allowing an overall precision, including ionospheric effects, of + or -2.4 cm. A three-frequency radiometer is also carried to observe along the altimeter propagation path at frequencies of 18, 21, and 37 GHz, providing a correction for the pulse delay due to water vapor in the troposphere. These two instruments are provided by NASA.

The satellite will carry a second altimeter provided by CNES. This is a single-frequency (13.6 GHz), solid-state altimeter which will use the same dish antenna as the NASA altimeter. Interference between the two altimeters will be avoided by not operating the two altimeters simultaneously. The French altimeter will be turned on for 1 day out of every 20 days, amounting to about 5 percent of the total available time.

Finally, the satellite will carry a variety of precision tracking systems for use in making the all-important determination of the position of the satellite. The primary NASA tracking system uses an on-board beacon, transmitting at two frequencies (150 and 400 MHz) to the Defense Mapping Agency's (DMA) TRANET system of ground receiving stations. The dual radio frequencies will allow first-order corrections for the influences of the ionosphere on the tracking signals. The tracking data received from this system will be analyzed and processed by groups at the Goddard Space Flight Center (GSFC) and the University of Texas to provide the accurate ephemeris for the satellite. The satellite will also carry a NASA laser tracking system consisting of an array of laser retroreflectors encircling the altimeter antenna. This system will be used with ground-based lasers to calibrate the altimeters from two calibration sites and may also be used to acquire laser tracking data useful in the precision orbit determination process.

A dual-frequency radio tracking system will be provided by the French. This system, called DORIS, will include a receiver on board the satellite to acquire signals from up to 50 beacons on the ground. The data from this system will be processed by the French DORIS Orbitography an Geopotential Evaluation group to derive seperate precision ephemeris solutions for the satellit to be used by the French to develop ocean topography from the CNES altimeter data.

A third precision radio tracking system will be carried by the satellite as a demonstration by NASA. A Global Positioning System (GPS) Demonstration receiver installed on the satellite will extract pseudo-ranges from the transmissions of the GPS satellites. Pseudorange data from four or more GPS satellites can be combined to determine the position and clock bias of th receiver. Pseudoranges to a ground receiver obtained simultaneously with the pseudoranges obtained on the TOPEX/POSEIDON satellite can be combined into another data type called double-differenced range. These new data types could allow the determination of the global orbit of TOPEX/POSEIDON to precisions as good as or better than the precisions obtained from the other data types being used on the TOPEX/POSEIDON mission.

The TOPEX Satellite. The satellite to be used to carry and support these science instruments will be purchased by NASA from U.S. industry. The satellite will be a modification of an existing design from one of three contractors who completed Phase B studies in early 1985. These studies, funded by NASA, provided details on the extent of the modifications required to match each satellite design to the TOPEX/POSEIDON requirements. The three companies are Fairchild Space Company of Germantown, MD, RCA Astro-Electronics Company of Princeton, NJ, and Rockwell International Satellite Systems Division of Downey, CA. All three have designs that will satisfy the mission requirements with reasonable levels of modifications.

Launch. The TOPEX/POSEIDON satellite will be launched by a European Ariane 4 launch vehicle. Launch will be from the Arianespace launch site at Kourou, French Guiana on the northeast coast of South America. Launch will be in early 1991, based on a Fiscal Year 1987 new start.

Orbit Design. Requirements and constraints have been used to established an orbit design space available for the TOPEX/POSEIDON mission (Reference 10). The orbit will be circular because the altimeter can not retain lock when the altitude rate is high. A baseline reference orbit within this orbit design space, at an altitude of 1334 km and an inclination of 63.13 deg, has been specified for use in TOPEX/POSEIDON design work. This orbit is periodic in 10 days, repeating its ground track exactly after 127 revolutions. The 10-day period gives a good trade-off between the frequency with which data at each point are acquired and the density of the grid of ground tracks with which the oceans are covered. Figure 2 illustrates the complete set of 127 ground tracks for this orbit, superimposed on a world map.

Another requirement is satisfied by this reference orbit because it places ground tracks directly over each of two calibration sites where the U.S. and France will install lasers and in situ instruments. Both of the site locations, Bermuda Island for the U.S. site and Dakar, Senegal for the French site, are tentative at this time. Figure 3 is a blow-up of the North Atlantic Ocean showing the ground tracks in greater detail and indicating the locations of the two verification sites and the launch site at Kourou.

The altitude of the orbit is higher than usual for Earth sensing satellites, decreasing the effects of atmospheric drag on the orbit. This aids the precision orbit determination process by reducing the effects of uncertainties in the drag modeling and by reducing the frequency of the orbit trim maneuvers which corrupt the orbit determination solutions. (Keeping the repeating ground tracks within 1 km of the required locations requires that the semi-major axis and the inclination to be maintained within strict tolerances.) The altitude selected is a compromise between this low-drag requirement and limits placed on the power and antenna size of the altimeter, both of which would increase with increasing altitude.

Precision Orbit Determination. As evidenced in Table 1, a major challenge to obtaining ocean current information from the TOPEX altimeter data is accurate determination of the satellite position at each moment of time (the orbit ephemeris). During the SEASAT program, impressive progress was made in the ability to reconstruct the satellite trajectory using laser and radiometric tracking data (Reference 4). However, considerable improvement in knowledge of the longer wavelength (greater than 1000 km) components of the Earth's gravity field is necessary to reconstruct the TOPEX radial ephemeris to the required accuracy. A 4-year program was started in 1984 by both NASA and European investigators to improve our knowledge of the gravity field at satellite altitude by at least a factor of two over the current best unclassified models. This field will be derived by using much more of the available satellite tracking data than have previously been used for gravity recovery. The improved gravity field, together with global tracking by the TRANET system, will allow the satellite's orbit to be determined with decimeter precision. If still better gravity fields become available later, the tracking data can be reanalyzed to produce even better orbits (Reference 11).

DATA PRODUCTS

The TOPEX/POSEIDON mission will provide both research and environmental data products. The primary data for scientific studies are the altimeter data which includes sea surface height, wave height, and wind speed. A Geophysical Data Record (GDR) is produced which includes verified measurements of these parameters plus precise positions of the satellite based on precision orbit determination. In addition, geoidal and tidal height at the satellite nadir point, plus all corrections applied to the satellite data, are included in the GDR.

Environmental data from the NASA altimeter (e.g., significant wave height and wind speed) will be processed and made available to the Navy's Fleet Numerical Oceanography Center within four hours of acquisition.

Extensive verification of the accuracy of sea surface height, significant wave height, wind speed, and precision orbit determination will be conducted during the first six months after launch. Geophysical parameters will be verified by comparison with in situ data including laser altitude measurements and local land and ocean buoy measurements of temperature, pressure, wave height and wind speed. Instrumentation on Bermuda Island and at a site near Dakar, Senegal will be the primary source of in situ data. The precise orbit measurements will be verified through comparisons of tracking residuals, and global and regional crossing-arc analyses.

Once the TOPEX measurements have been verified, production of GDRs will begin. Verification after the initial 6-month period will consist primarily of monitoring the quality of the geophysical measurements and comparisons of crossing-arc and repeat-track residuals. If this monitoring activity reveals unexplained accuracy deviations, then a re-verification effort, similar to that performed during the first 6 months, will be considered. NASA is responsible for verification and calibration of the U.S. sensors and CNES is responsible for verifying and calibrating the French instruments.

The TOPEX Ground Data System (GDS) acquires telemetry and tracking data, develops and sends commands to the satellite, monitors the health of the satellite and sensors, and processes and distributes scientific and engineering data. This process is illustrated in Figure 4. The core of the GDS is the TOPEX Data System (TDS) which is resident at JPL. Telemetry data from the satellite will be acquired through NASA's Tracking and Data Relay Satellite System (TDRSS). Commands are sent to the satellite via a TDRSS forward link. Data from CNES sensors will be routed to Toulouse, France. Operational tracking data from TDRSS is routed to GSFC for operational orbit determination processing. TRANET tracking data will be acquired by DMA and passed to GSFC for precision orbit determination.

Data from the U.S. sensors is processed at JPL. The primary data product for research purposes is the GDR. The GDR is generated on a global basis as an archival data product. GDR production will begin 6 months after launch. Each GDR will contain about 24 hours of data and will be available about 1 month after receipt of the raw data. The GDR is sent to the NASA Ocean Data System for distribution to the TOPEX science investigators, to the National Oceanic and Atmospheric Administration (NOAA) for distribution to the general science community, and to CNES for distribution through the French data system to the French-selected science investigators. During the first 6 months of the mission, an Interim Geophysical Data Record (IGDR) will be produced. Data on this record will be unverified and will include satellite positions from the operational orbit ephemeris rather than the precision orbit ephemeris. The IGDRs will contain 24 hours of data and will be available about 5 days after receipt of the data. These IGDRs will be replaced with GDRs at a later date when the verification process is complete.

PROGRAM STATUS

The TOPEX Project is managed by the Jet Propulsion Laboratory for NASA and the POSEIDON Project is managed by the Toulouse Space Center for CNES. The TOPEX/POSEIDON cooperative mission will be operated under a Memorandum of Understanding between NASA and CNES. Formal approval and funding for the TOPEX Project is expected in October of 1986. This would allow a launch in early 1991. The mission duration is set at 3 years to allow the temporal behavior of the ocean currents to be observed in the data. The potential for an extension of operations for 2 more years is built into the mission so that if all goes well, a full 5 years of data may be gathered (Reference 9). An announcement of opportunity soliciting proposals for scientific research based on TOPEX/POSEIDON data will be issued jointly by NASA and CNES in early 1986.

The TOPEX/POSEIDON mission timing and data distribution are integrated with the intense world oceanographic effort being planned for the decade beginning in 1985. This space mission will make important contributions to the Global Habitability Program of NASA, the International Biogeochemical Program of the International Council of Scientific Unions, and the World Climate Research Program of the World Meteorological Organization (Reference 12). Of these programs, the latter is the most advanced in its planning (Reference 13). In particular, two components of the World Climate Research Program will benefit from TOPEX/POSEIDON observations: The World Ocean Circulation Experiment, which has the goal of understanding ocean circulation sufficiently well to predict its response to external forcing, requires global measurements of surface geostrophic currents produced from satellite altimeter data; and the Tropical Oceans Global Atmospheres Experiment, which has the goal of understanding the interaction of the tropical oceans with the atmosphere, requires measurements of surface geostrophic currents in the tropical regions. In return, TOPEX/POSEIDON scientists will benefit from the extensive in situ measurements of currents and density being planned for the other experiments.

The TOPEX/POSEIDON mission is expected to enhance the data returned from the Earth Resources Satellite-1 and the Navy Remote Ocean Sensing Satellite programs. Both of these satellites will also carry altimeters, but in orbits less well determined than that of TOPEX/POSEIDON. By flying at the same time as these satellites, the TOPEX/POSEIDON altimeter data can be used to calibrate the data from them, allowing currents and ice to be accurately mapped at higher latitudes than are reached from the TOPEX/POSEIDON orbit. In addition, the combination of data from the three altimeters will provide more frequent measurements of ocean currents useful for mapping smaller features of the current system.

The concurrence of these programs, as they are now planned, is illustrated in Figure 5 (Reference 13). Note that the concurrence of TOPEX/POSEIDON with these other programs has slipped somewhat, but the overlap of the programs as now planned is sufficient to obtain the desired enhancement of the data from each.

The benefits to be derived from utilization of the TOPEX/POSEIDON data are wideranging and important. Variations in ocean circulation are linked to El Nino and associated floods and droughts, to the greenhouse effect and associated changes in global temperature and precipitation, and to agricultural productivity. Variations in ocean circulation also change temperatures and redistribute nutrients, both of which affect fisheries and the marine food web. The fate of pollutents and the quality of the marine environment are controlled by the ocean circulation. Variations in ocean circulation affect the efficiency of marine transportation and offshore operations for petroleum and mining, and influence effective management and exploitation of the Exclusive Economic Zone.

CONCLUSIONS

The TOPEX/POSEIDON mission as it is now planned and scheduled is a unique opportunity to build on past experience and cooperate with other contemporary programs to gather a highly useful set of scientific observations of the world ocean. The program is sharply focused to perform the ocean topography measurement with the precision necessary to resolve the signature of the ocean currents at minimum cost with high reliability. The primary sensors are based on proven heritage from past programs and the satellite bus is a modification of an "off-the-shelf" satellite of proven design. The program includes extensive planning and development for data handling and processing to ensure that the data acquired will be available for scientific use in a timely manner and in a useful form. The TOPEX/POSEIDON data set will be a keystone in the global effort to more completely understand critical elements of our environment.

The success of this international program, in concert with other satellite and in situ programs, will result in an improved ability to model the climates of the ocean and the atmosphere including their interactions. These models should lead to improved weather forecasting, especially over longer time spans of weeks, months and perhaps years.

ACKNOWLEDGMENT

The research described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration, with technical assistance from the Goddard Space Flight Center, the University of Texas, and the University of Colorado. Some material was also obtained from the Centre Spatial de Toulouse of the Centre National d'Etudes Spatiales in Toulouse, France.

REFERENCES

1. "Scientific Plan, World Ocean Circulation Experiment," G. T. Needler, Institute of Oceanographic Sciences, Wormley, England, December 1985.

2. "Large-Scale Oceanographic Experiments in the WCRP," Report of the JSC/CCCO Study Conference in Tokyo, 10-21 may 1983, WCRP Publications Series No. 1, June 1983.

3. "Satellite Altimetric Measurements of the Ocean," Report of the TOPEX Science Working Group, Jet Propulsion Laboratory report 400-111, March 1, 1981.

4. "TOPEX - A Spaceborne Ocean Observing System," George H. Born, Robert A. Stewart, and Charles A. Yamarone, Progress in Astronautics and Aeronautics, V. 97, American Institute of Aeronautics and Astronautics, 1985.

5. "Seasat Special Issue I, Geophysical Evaluation," Journal of Geophysical Research, Volume 87, Number C5, April 30, 1982.

6. "Seasat Special Issue II, Scientific Results," Journal of Geophysical Research, Volume 88, Number C3, February 28, 1983.

7. "TOPEX/POSEIDON Joint Working Group Final Report," Jet Propulsion Laboratory report JPL D-2035, December 1984.

8. "TOPEX/POSEIDON Mission Description," Jet Propulsion Laboratory report JPL D-601, Revision B, December 1985.

9. "TOPEX Project Requirements and Constraints," Jet Propulsion Laboratory report JPL D-2555, November 1985.

10. "The Application of Periodic Orbits to TOPEX Mission Design," David L. Farless, AAS/AIAA Astrodynamics Conference Paper No. AAS 85-301, Vail, Colorado, August 12-15, 1985.

11. "TOPEX: Observing the Oceans From Space," George H. Born, Carl Wunch, and Charles A. Yamarone, EOS, Transactions, American Geophysical Union, Vol. 65, No. 28, July 10, 1984.

12. "U.S. World Ocean Circulation Experiment Planning Report Number 1," U.S. WOCE Scientific Steering Committee, July 1985.

13. "Oceanography from Space, A Research Strategy for the Decade 1985-1995," Parts 1 and 2 of a report prepared by the Satellite Planning Committee of the Joint Oceanographic Institutions Incorporated, July 1984.

TABLE 1. TOPEX Height Measurement Error Budget

Error Source	Uncertainty (cm, 1 sigma)	Decorrelation Distance (km)
ALTIMETER		
Instrument Noise	2.0	20
Bias Drift	2.0	(many days)
MEDIA		
EM Bias	2.0	200-1000
Skewness	1.0	200-1000
Troposphere - Dry	0.7	1000
Troposphere - Wet	1.2	50
Ionosphere	1.3	20
ORBIT		
Atmospheric Drag	1.0	>10,000
Solar Radiation	1.0	10,000
Earth Radiation	<1.0	10,000
Gravitational Parameter	2.0	10,000
Gravity Model	10.0	10,000
Earth and Ocean Tides	1.0	10,000
Troposphere	1.0	10,000
Station and Satellite Clock	1.0	10,000
Station Location	5.0	10,000
Higher Order Ionosphere	5.0	10,000
RSS ABSOLUTE ERROR	13.3	

Major Assumptions

1. Dual frequency altimeter.
2. Dual frequency radiometer.
3. Upgraded TRANET tracking system with 40 stations.
4. Altimeter data averaged over 3 sec.
5. H(1/3) = 2 m, wave skewness = 0.1.
6. Tabular corrections based on limited waveform-tracker comparisons.
7. Altitude = 1330 km.
8. No anomalous data, no rain.
9. Improved gravity model.
10. +or- 3 mbar surface pressure from weather charts.
11. 100 microsec spacecraft clock.

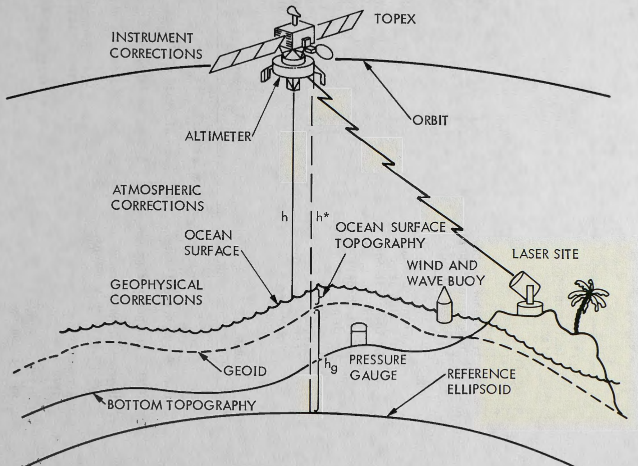

FIGURE 1. Sea Surface Height Measurement Schematic.

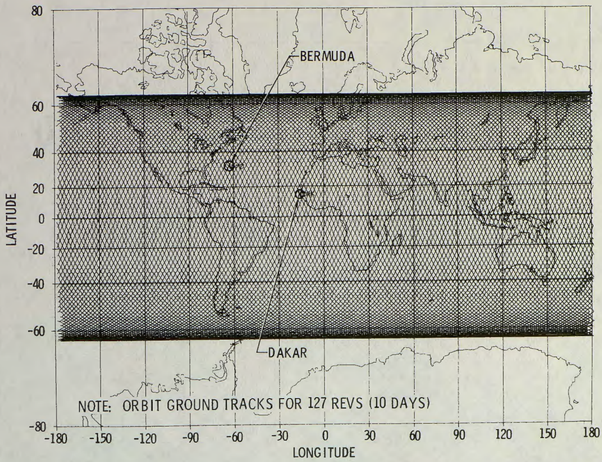

FIGURE 2. Ground Tracks for the TOPEX/POSEIDON Reference orbit.

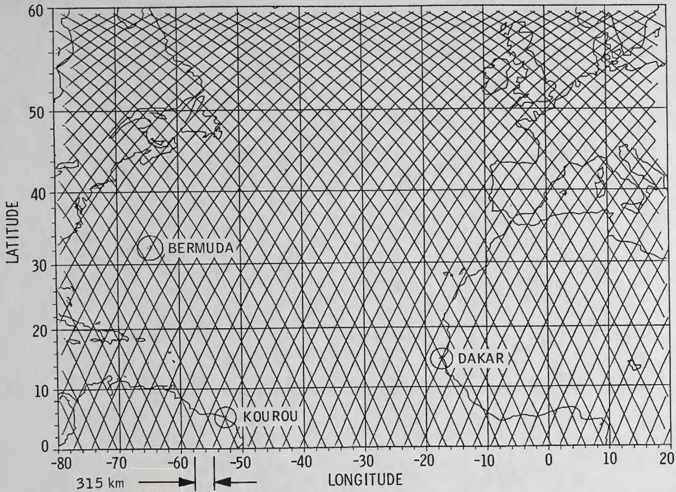

FIGURE 3. North Atlantic Ground Tracks for the TOPEX/POSEIDON Reference orbit.

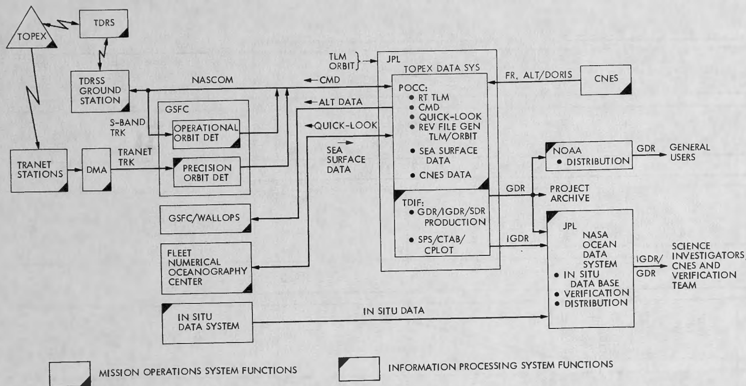

FIGURE 4. The TOPEX Ground Data System.

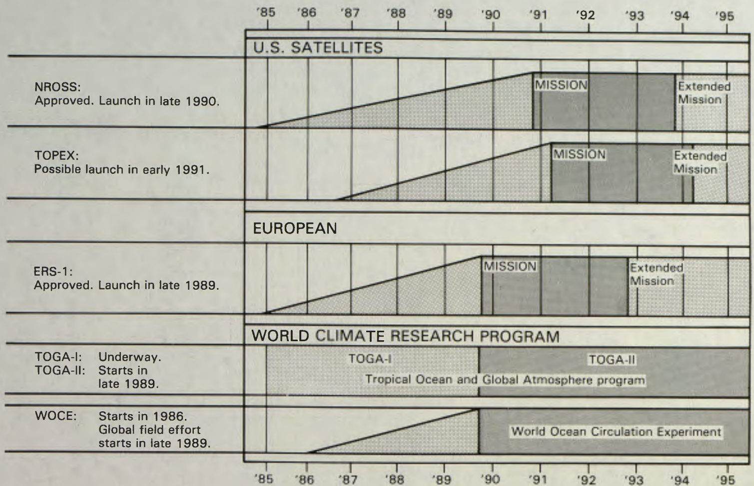

FIGURE 5. Timelines for World Ocean Programs.